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SPATIAL AND TEMPORAL VARIATIONS OF THE PALMER DROUGHT SEVERITY INDEX IN SOUTH-EAST HUNGARY

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Összefoglalás - Havi száraz és nedves anomáliák térbeli és időbeli jellemzőit elemezzük a Körös-Maros köze (gyakorlatilag Csongrád és Békés megye) területén, amelyet a termesztett növények nagy területi aránya jellemez. A nedvességi viszonyokat a Palmer-féle aszályossági index (PDSI) felhasználásával számszerűsítjük. A Palmer-modell számításait az 1951-1990 évek (főként a tenyészidőszakra kiterjedő) havi adatsoraira végeztük el a térség 17 állomására. Az alapvető statisztikai jellemzők, ill. a térbeli és időbeli korrelációk megállapítása mellett faktoranalízis segítségével alrégiókat is meghatároztunk, amelyeken belül a PDSI értékek hasonló fázisban ingadoznak. Vizsgáltuk a nyári félévben a térségen belül fennálló egyidejű korrelációk szorosságát, valamint a kiszáradási folyamat kezdetén (áprilisban) megfigyelt állapot hatását a rákövetkező hónapok PDSI értékeire. A hosszabb, 1881-1990 évek idősoraira elemeztük a lassúbb, egyirányú változásokat, valamint a teljes időszak átlagától szignifikánsan eltérő szakaszok hosszát.

Summary - Spatial and diachronic characteristics of monthly dry and wet anomalies are examined in the Körös-Maros Interfluve Area (in the practical calculations, Csongrád and Békés counties, on the Great Hungarian Plain), characterized by high proportionality of managed vegetation. Assessment of humidity conditions is performed by employing the Palmer Drought Severity Index (PDSI). Palmer's model is applied to monthly data (mostly in the vegetation period) for the period of 1951-1990 at 17 stations of the region. Besides computation of basic statistics and determination of the spatial and temporal correlations, factor analysis is also employed to define subareas in the region, inside of which PDSIs covary in time. Synchronous correlations between the stations of the region and the effect of April conditions on the following months PDSI values are also investigated. Long-term, unidirectional changes and also the length of periods are demonstrated, exhibiting averages which are significantly different from that case in which the whole period of 1881-1990 is covered.

Key words: Palmer Drought Severity Index - time and space correlations - factor analysis - long-term climate variations - Körös-Maros Interfluve Area - Hungary

1. INTRODUCTION

There has been an increasing concern about the observed climate variations since the preindustrial period. The distribution of world agriculture shows an adaptation to the present-day climate patterns, but this situation could change in relation to the likely global warming (*IPCC, 1996*).

Environmental and economic effects of the climate variations can be apparent first of all, through the changes of natural water supply, river discharges, average crop yields, as well as natural vegetation. Hence, a new chapter in landscape evaluation is indicated by the recognition that climate is subject to changes, also on a relatively short term. Its alterations considerably affect several processes of the landscape system. A major temperature increase greatly controls the heat and water budget of each landscape and has fundamental impacts on agriculture. On a longer time scale, a new balance of water and heat, as key factors of the surface formation, may affect morphological features of landscapes, too. Besides that, apart from global trends, climate of Hungary inclines to shorter or longer aridity and to irregular distribution of the annual precipitation.

2. THE KÖRÖS-MAROS REGION

The region, selected for the investigation is the Körös-Maros Interfluve Area (*Fig. 1*), as a medium-sized landscape (in practice, a somewhat broader area, namely Csongrád and Békés counties), which has always been characterized by high proportionality of managed vegetation. Recently, 79 % of the 8,650 km^2 productive land (which is 88 % of the total geographical area) is arable, whereas the agricultural area covers 93 % of the productive land. Proportion of inhabitants employed in agriculture is about 200 % of the national average. Hence, the investigated area is covered, in overwhelming majority, by seasonal vegetation, which is highly vulnerable to climate variations and also to the non-climatic conditions of plant management.

The plain is part of the Maros-Tisza-Körös region which consists of young sediments. The territory of this geomorphological area is 5,000 km^2. Comparing to the neighbouring physical geographical lands, this region has "ridge" character. Consequently it is due to be named "Békés-Csanádi" ridge, as well. The total territory, together with the additional regions of both counties, is approximately 10,000 km^2. The selection of the region has also been motivated by the recent definition of a National Park in the area and by the

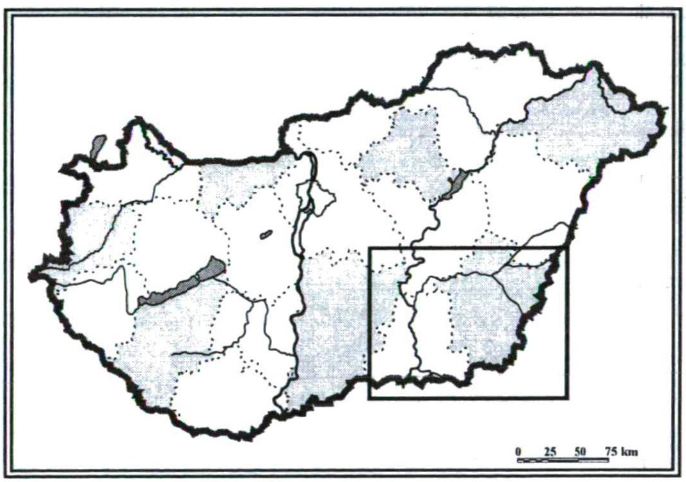

Fig. 1 The location of restricted area

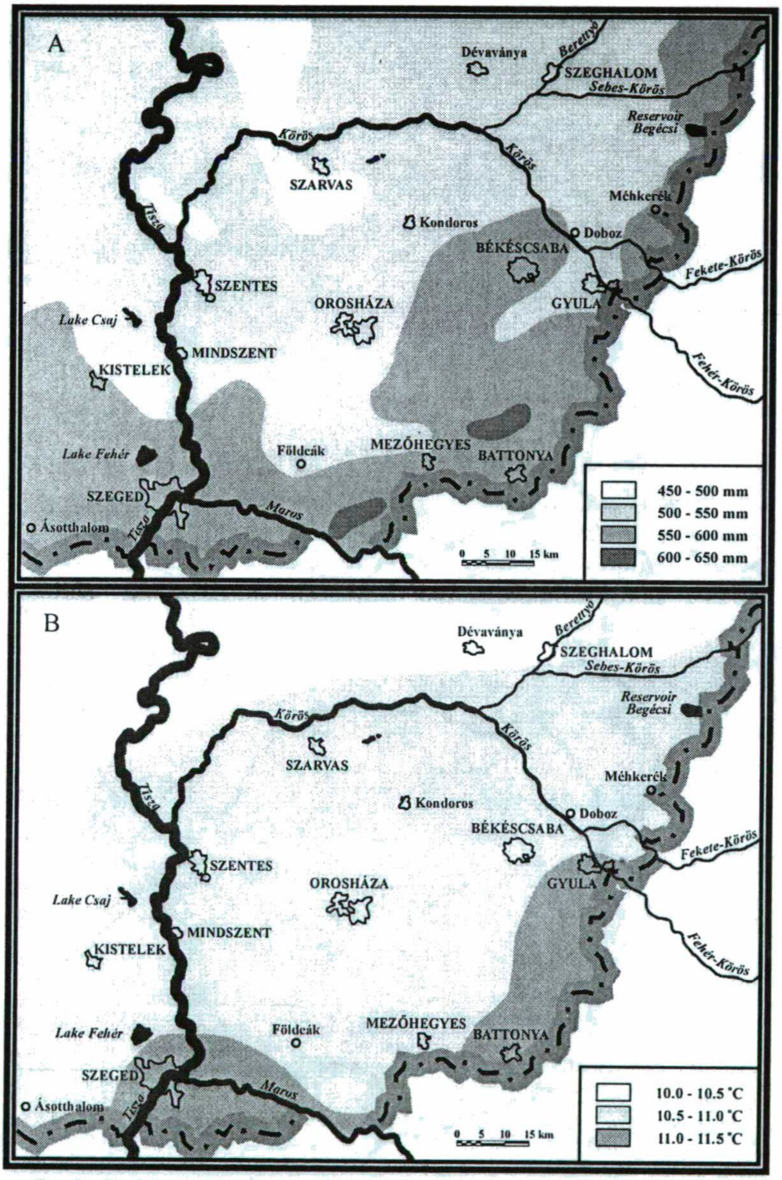

Fig. 2a-2b Climatic distribution of annual precipitation totals (A) and annual mean temperature (B) in the Körös Maros region

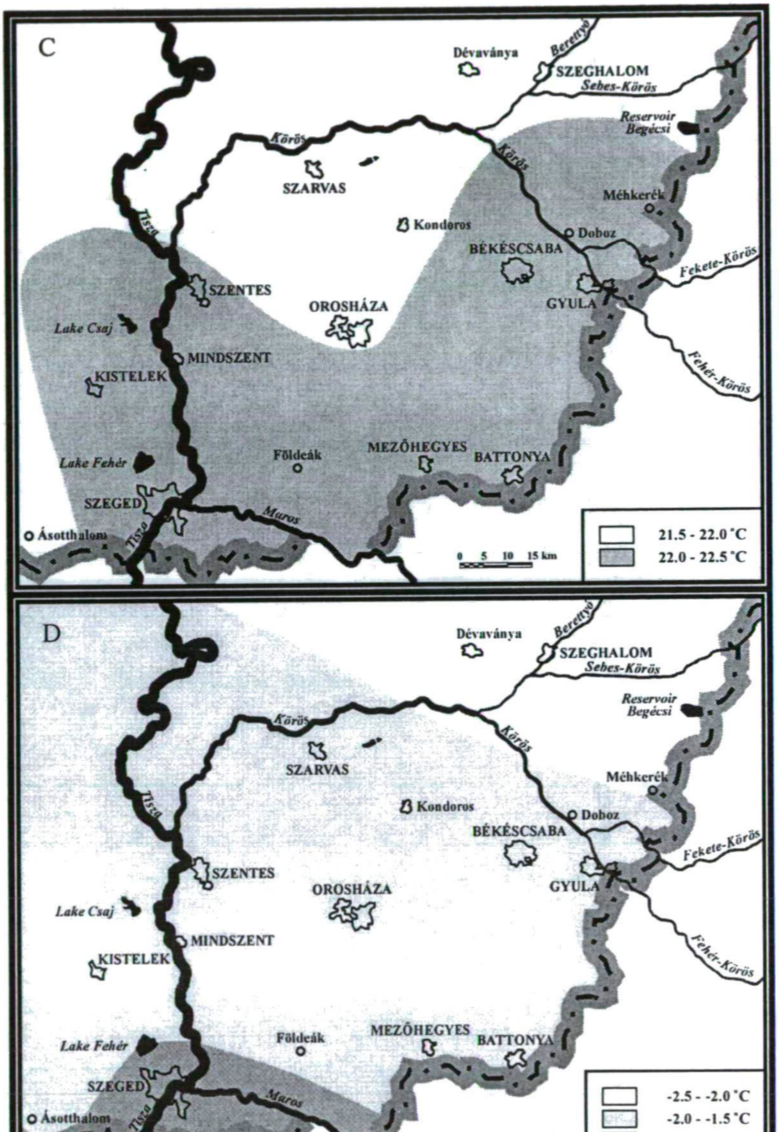

Fig. 2c-2d Monthly mean temperature in July (C) and in January (D) in the Körös Maros region international coopearation called Danube - Maros - Tisza Euroregion, as well.

The effect of the isolated Transylvanian mountains, in addition to the typical low-land climate characteristics, can also be observed in the climate of the region. The spatial distribution of precipitation is fairly changing. The precipitation amount increases from northwest towards southeast. The annual average precipitation is about 550-600 mm in southeast, even over 600 mm at some places. On the other hand, it is less than 550 mm in the most part of the region moreover, less than 500 mm in the northwestern part of the Körös-Maros region (*Fig. 2a*).

On the basis of these differences two climatic zones can be experienced in this region: the northwestern part is dry with hot summer, while the southeastern part is only moderately dry with similarly hot summer. The annual mean temperatures are shown in *Fig. 2b* (*Kakas*, 1960). The annual mean maximum temperature in this region is the highest in Hungary (*Fig. 2c*). The mean temperature of the coldest month is below 0°C, that is to say the region shows continental character (*Fig. 2d*).

Loose soils, which are permeable or semipermeable to water, do not make possible development of permanent watercourses on the surface. As compared to the annual mean temperature (10.5-11.0°C), the annual mean precipitation amount is far from the optimum. The outflow coefficient is between 3-5 %. The yearly amount of evaporation is regularly higher than that of precipitation. Consequently the aridity index is generally higher than 1. Some years are characterized with extreme aridity which correspond to semi-desertic conditions (*Makra et al.*, 1986).

The medium-sized region investigated (first of all its southwestern part) is extremely inclined to drought which causes the most serious damage in agriculture. However, irrigation is prevented by the lack of water. On the other hand, difficulties in connection with inland waters should also be mentioned. Although the region examined is characterized by scarcity of water, regularly in spring inland waters appear to some extent.

Inland waters in a given catchment area are surplus waters appearing either on the surface or in cracks of the soil, which raise difficulties to developing of plants (*Pálfai*, 1988). Appearance of inland waters is changeable in time and space, since they may come into being on the one hand in dry periods on the other hand hardly only in polder areas.

Soil formation factors here are favourable to the development of chernozem. The most fertile chernozem soils of Hungary can be found in this region. Development of various chernozems, under much the same climatic conditions, is directed by geological structure and hydrographical factors. Characteristic soil types in the region are shown in *Table 1*.

3. THE PALMER DROUGHT SEVERITY INDEX

There is no universal quantitative definition of droughts. In the present study, drought is considered as a meteorological anomaly characterized by a prolonged and abnormal moisture deficiency (*Palmer*, 1965; *Dalezios et.al.*, 1991). Nevertheless, a distinction should also be made between hydrological drought and agricultural drought. Specifically, hydrological drought can be considered as a period during which the actual water supply is less than the minimum water supply necessary for normal operations in a particular region. Agricultural drought is characterized in terms of crop failure and exists when soil moisture is depleted so that crop yield is reduced considerably.

Table 1 Soil types at the meteorological stations examined

Geographic coordinates		*Station*	*Type of soil*
latitude	**longitude**		
46°12'	19°47'	Ásotthalom	sandy coarse soil
46°16'	21°03'	Battonya	solonetzic meadow chernozem
46°40'	21°07'	Békéscsaba	meadow chernozem with salt accumulation in the deeper layers
47°01'	20°58'	Dévaványa	meadow soil
46°43'	21°13'	Doboz	meadow soil
46°17'	20°30'	Földeák	meadow chernozem (the term "meadow" is related to hydromorphic character)
46°39'	21°16'	Gyula	meadow soil
46°26'	19°50'	Kistelek	humous sandy soil
46°45'	20°50'	Kondoros	lowland chernozem
46°46'	21°24'	Méhkerék	meadow solonetz
46°19'	20°49'	Mezőhegyes	lowland chernozem
46°30'	20°11'	Mindszent	meadow alluvial and alluvial meadow soil
46°34'	20°40'	Orosháza	lowland chernozem
46°52'	20°32'	Szarvas	meadow chernozem with salt accumulation in deeper layers
46°15'	20°10'	Szeged	solonetzic meadow; meadow, alluvial soil
47°01'	21°10'	Szeghalom	meadow soil
46°39'	20°15'	Szentes	meadow soil

The immediate meteorological causes of drought involve a number of factors. A stable high-pressure air-mass with descending air and low humidity is relatively free of clouds. If this air mass stagnates or moves slowly across an area because of atmospheric circulation patterns, the region, over which it lingers, will receive substantial sunshine and generally dry air with little or no rain. Once established, this condition has a tendency to persist, resulting in drought. Although a single drought is a phenomenon of shorter time scales, the frequency of drought can vary on decadal or longer scales, especially at low geographical latitudes.

To detect the onset of meteorological droughts and assess their severity, an "objective" index is used, namely the Palmer Drought Severity Index (PDSI). The PDSI is one of the few general indices which does address some of the elusive drought properties such as intensity, onset time and end time. Although the PDSI is referred to an index of meteorological drought, the procedure considers precipitation, evapotranspiration, and soil moisture conditions, which are determinants of hydrological drought and, indirectly, of agricultural drought (*Palmer*, 1965; *Alley*, 1984; *Karl*, 1986). In addition, the PDSI is standardised for different regions and time periods which is a necessary requirement for the areal assessment of droughts.

The basic concepts and steps for computing the PDSI are presented here. The whole procedure is described by *Palmer* (1965).

Step 1: Hydrological Accounting. The computation of the PDSI begins with a climatic water balance using long series of monthly precipitation and temperature records as inputs. An empirical procedure is used to account for soil moisture storage by dividing the soil into two arbitrary layers. The upper layer is assumed to contain 25 mm of available moisture at field capacity. The loss from the underlying layer depends on the initial moisture content as well as on the computed potential evapotranspiration (PE) and the available water capacity (AWC) of the soil system. In the present calculations of PDSI, AWC values of 170 - 220 mm are used according to the soil types, presented in *Table 1*. Runoff is assumed to occur, if and only if, both layers reach their combined moisture capacity, AWC. In addition to PE, three more potential terms are used and they are defined as follows: Potential Recharge (PR) is the amount of moisture required to bring the soil to its water holding capacity. Potential Loss (PL) is the amount of moisture that could be lost from the soil by evapotranspiration during a zero precipitation period. The Potential Runoff (PRO) is defined as the difference between the potential precipitation and the potential recharge.

Step 2: Climatic Coefficients. This is accomplished by simulating the water balance for the period of available weather records. Monthly coefficients are computed as proportions between climatic averages of actual versus potential values of evaporation, recharge, runoff and loss, respectively.

Step 3: CAFEC Values. The derived coefficients are used to determine the amount of precipitation (P) required for the CAFEC (Climatically Appropriate For Existing Conditions), for instance "normal" weather during each individual month.

Step 4: Moisture Anomaly Index. In each month, the difference between the actual and CAFEC precipitations is an indicator of water deficiency or surplus for that month at the studied area. This is expressed as $D=P-P$. These departures are converted into indices of moisture anomaly as $Z=K(j)D$, where $K(j)$ is a weighting factor for the month j which takes into account also the spatial variability of the departures (D).

Step 5: Drought Severity. In the final step the Z-index time series are analyzed to develop criteria for the beginning and ending of drought periods and a formula for determining drought severity. The following empirical expression for drought severity is used :

$$X_j = 0.897X_{j-1} + Z_j/3 \qquad (1)$$

where Zj represents values of the moisture anomaly index for the dry intervals and Xj is the value of PDSI for jth month. The classification of weather using PDSI is given by *Palmer* (1965) as a stepwise gradation from PDSI < -4 (extreme drought) to PDSI > +4 (extreme wet). At *Fig. 2a* and *2b* fluctuation of the PDSI can be seen in the period of 1881-1990. The ensemble or the 12 parallels indicate the PDSI values of the individual months. It is worth to note that these monthly values fluctuate rather parallelly at the intra- and interannual time scales. Consequently, legends are omitted at *Fig. 3a* and *3b*.

4. SPATIAL VARIATIONS AND SHORT-TERM FLUCTUATIONS

Short-term variability is analysed for 11 stations of the Körös-Maros Region (Szeged, Szentes, Szarvas, Békéscsaba, Földeák, Mezőhegyes, Orosháza, Mindszent, Kondoros, Gyula, Battonya) as well as six other stations (Kistelek, Szeghalom, Ásotthalom, Dévaványa, Méhkerék, Doboz) situated in the vicinity of the strictly defined target area for the period of 1952-1985. These calculations include some basic statistics of the distributions including also the test for normality, as well. Spatial and temporal correlations aim to characterise how variations in this relatively small area are interrelated between each other and which part of the year is mostly responsible for the water availability anomalies of the vegetation period. Spatial relations are more thoroughly analysed by spatial factor analysis with the intention to determine objective subregions by applying the PDSI.

4.1 Basic statistics

In principle, PDSI is a non-seasonal characteristic of water availability, but it is worth checking if independence of season really fulfilled for the basic statistical parameters, for example average, standard deviation and standard skewness. In the following, these parameters of PDSI are analysed in four months, namely in April, June, August and October of the vegetation period.

Table 2 indicates that for the averages the assumed universality is fairly valid: deviations from the mean are not large in the different months. In case of standard deviations, however the picture is not so unequivocal. The minimum among these four months is in June at each station and the maximum occurs mainly in August. Although the differences between the highest and lowest standard deviations are themselves non-significant (according to the F-test), the identical course of the values in the four months at the four stations should be considered as regular.

For standard skewness there is an increasing tendency from negative values in April to the positive ones towards the end of the vegetation period. Negative standard skewness values in April (with the exception of Szarvas) indicate that lower (relatively dry) values are more

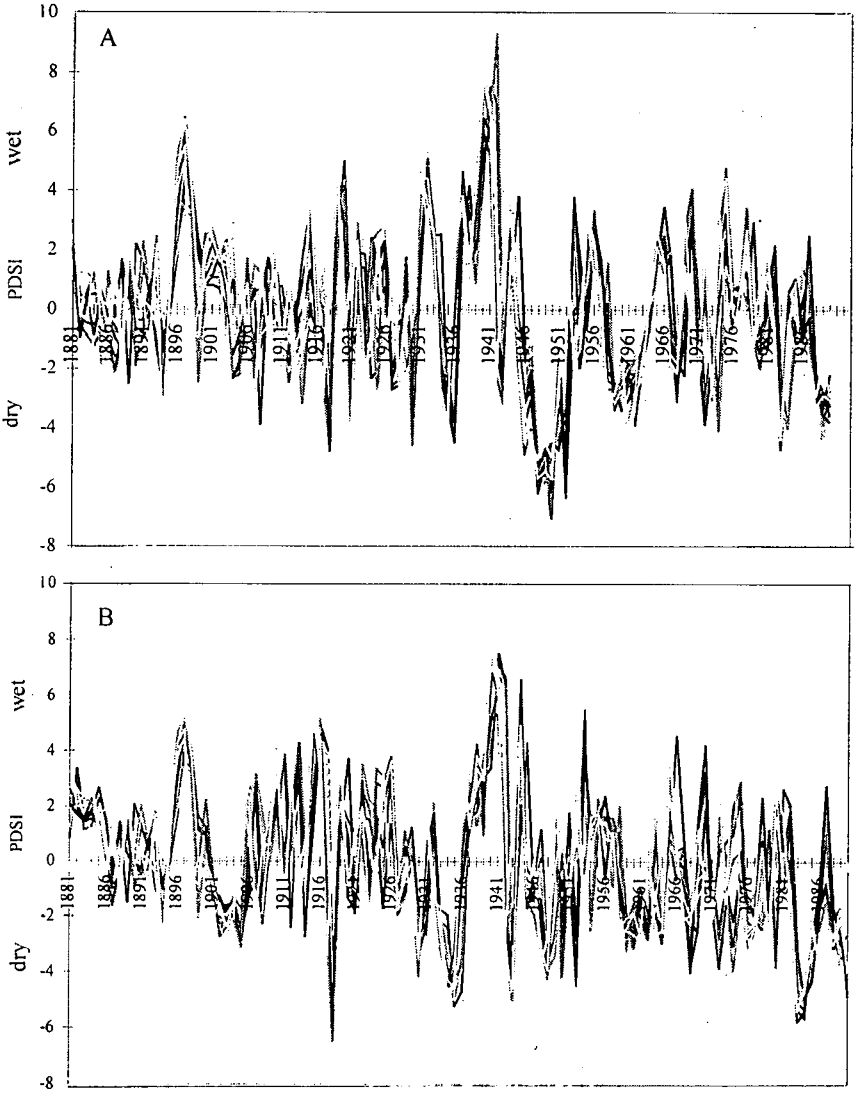

Fig. 3a-3b The parallel fluctuation of the monthly PDSI values at the intra- and interannual time scales, 1881-1990. A) Szeged; B) Szarvas frequent, but high extremes are more severe. In those months with positive skewness the situation is generally the opposite: high (wet) extreme values are more frequent, but strong droughts occurred in the investigated 1951-90 period.

Table 2 Basic statistics of the PDSI and results of normality tests (probability in %)

	Battonya				*Méhkerék*				*Szarvas*				*Szeged*			
	April	*Jun*	*Aug*	*Oct*	*April*	*Jun*	*Aug*	*Oct*	*April*	*Jun*	*Aug*	*Oct*	*April*	*Jun*	*Aug*	*Oct*
Mean	-0.00	-0.23	-0.04	0.19	-0.17	-0.13	0.06	-0.01	-0.32	-0.00	0.13	-0.01	-0.02	-0.11	+0.00	-0.01
St. dev	1.75	1.57	1.95	1.85	1.68	1.62	1.95	2.05	1.60	1.48	1.98	1.79	2.09	1.75	1.94	1.86
Skewn.	-0.33	0.21	0.04	0.10	-0.50	0.20	0.47	0.46	0.14	0.33	0.47	0.94	-0.87	-0.39	0.08	0.93
K-S test	99	25	68	94	92	68	67	64	39	23	90	53	93	99	81	34
χ^2 *test*	55	69	35	10	12	4	49	8	2	5	31	45	20	63	5	5

This cyclicity also supports that in the followings we analyse the PDSI statistics separately for the selected months.

As far as the normality of the distributions is concerned, the Kolmogorov-Smirnov (K-S) test shows that, normality is a likely assumption for PDSI, although probability of this decision is rarely higher than 90 %. According to the χ^2-test, normality is not so unequivocal. From the 16 investigated ones the normality is fulfilled in 10 cases, but the rest is distributed rather irregularly between the sites and the months of the vegetation period. Without monthly separation, the series exhibit definitely irregular, non Gaussian distribution (*Mika et al.*, 1994)

4.2 Space and time correlations

Spatial correlations are computed for synchronous monthly PDSI values of four stations, Szeged, Szarvas, Méhkerék and Battonya, situated more or less regularly at the four "edges" of the region. Analysing spatial correlations (*Table 3*) corresponding to identical months of the year, they demonstrate moderate strength of connections. The correlations are always positive and significant at the 1 % significance level, which is not surprising at all. On the other hand, the numerical values between 0.43 and 0.83 suggest that even in this small region (10,000 km^2, as already indicated) the drought/wetness conditions may vary, likely due to the spatial irregularity of precipitation.

If comparing the values in the different months, one can establish that they are relatively high in April and August (0.65 - 0.83), but lower (0.43 - 0.70) in the climatically wet June and the highly variable October. This means for these two months that in some years the dry or wet periods occur in the region, but not in other cases.

Another interesting question, related to dry or wet anomalies, is how strongly the conditions at the end of previous cold half-year determine those in the forthcoming vegetation period. In this respect, correlations between April and other months are displayed below the diagonal of *Table 3*. The 5 % correlation threshold is 0.34, which is surpassed at three stations from the four investigated cases for June (r = 0.38 - 0.47) and reached in one station for August. Hence, PDSI values of October and August are determined mainly by the moisture balance of the vegetation period, itself.

Table 3 Spatial (synchronous) and temporal (retarded) correlations of the PDSI in four selected stations of the Körös-Maros Region

		BATTONYA				***MÉHKERÉK***				***SZARVAS***				***SZEGED***			
		April	***Jun***	***Aug***	***Oct***	***April***	***Jun***	***Aug***	***Oct***	***April***	***Jun***	***Aug***	***Oct***	***April***	***Jun***	***Aug***	***Oct***
BATTONYA	***April***					0.73				0.77				0.78			
	June	0.38					0.46				0.52				0.55		
	August	0.34						0.70				0.67				0.71	
	October	0.02							0.70				0.49				0.64
MÉHKERÉK	***April***									0.83				0.72			
	June					0.43					0.51				0.55		
	August					0.22						0.65				0.70	
	October					0.18							0.44				0.57
SZARVAS	***April***													0.77			
	June									0.26					0.61		
	August									0.06						0.69	
	October									-0.09							0.43
SZEGED	***April***																
	June													0.47			
	August													0.22			
	October													-0.06			

We should note that these correlations are naturally lower than those published by *Mika* (1996) for other stations of Hungary, since those values were increased by the low-frequency variations of the 110 years series, while the present correlations characterise only 40 years.

4.3 Regionalisation by factor analysis

One of the best methods studying time series data for a large number of stations or grid points, where strong spatial and temporal correlation prevails, is *Factor Analysis* (see e.g. *Bartzokas and Metaxas*, 1993). One of the main benefits of this method is the reduction of the initial variables to much fewer uncorrelated ones, namely the factors. In this way, regions can be defined where, for any point within each region, the analysed meteorological variable covaries. Each original variable, P_i, i=1, 2, ..., n, can be expressed as $P_i=a_{i1}F_1+a_{i2}F_2+...+a_{im}F_m$ (m<n), where F_j, j=1, 2,...,m, are the factors and a_{ij} are the loadings. One important stage of this method is the decision for the number (m) of the retained factors. On this matter, many criteria have been proposed. In this study, the *Guttman criterion* or *Rule 1* is used (*Bartzokas and Metaxas*, 1993) which determines to keep the factors with eigenvalues > 1, and neglect the ones that do not account for at least the variance of one standardized variable. Another vital stage in this analysis is the so-called rotation of the axes (factors). This process achieves a discrimination among the loadings which makes the rotated axes easier to interpret. In this analysis the *Orthogonal Varimax Rotation* has been applied, which keeps the factors uncorrelated. In general, there is no guarantee that the evaluated factors represent dynamically existing entities, but, as with any statistical tool, it is important to determine whether or not the results have any physical meaning.

Factor analysis defined different numbers of subareas in the different months of the year. The eigenvalues and the percentages, explained by the retained and rotated factors for PDSI for each month are shown in *Table 4.* It is found that the retained factors explain 71 - 78 % of the total variance exhibited by all initial variables. The number of retained factors varies between 1 and 3. The first case means that there is no internal structure within the region as far as the 17 stations are able to represent it. One region is found mainly in the relatively low-precipitation periods of the year (January, February, March, April, August and December). Two subregions occur in May, July, September, October and November. In June, the analysis yields 3 regions, in good coincidence with the phase of the annual maximum of precipitation.

Table 4 The significant eigenvalues and the total percentage of variance explained by the retained and rotated factors

	Jan	*Feb*	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
1	13.2	13.2	13.2	13.4	10.8	9.9	10.8	12.1	11.1	12.2	11.5	13.2
2					1.9	2.0	1.2		1.4	1.1	1.1	
3						1.0						
Expl. var.	78	78	78	79	75	76	71	71	74	78	74	78

Although the method of Factor Analysis derives the regions from similarities and differences on time scales of climate fluctuations, and also, the regions differ considerably from one month to the other, it is worth displaying the obtained regions, as well (*Fig. 4a-4f*). Central parts of the subregions are indicated by the 0.8 factor loading isolines (except for one region in June, for which this value is only 0.6).

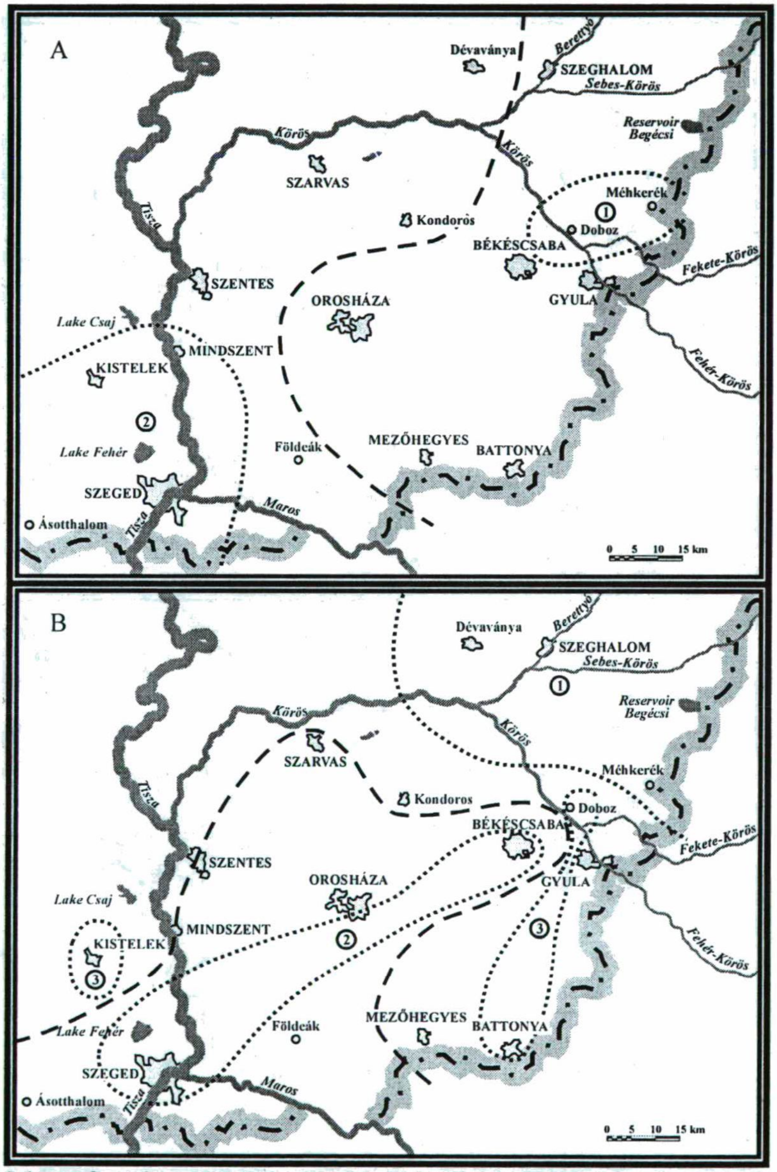

Fig. 4a-4b Subareas formed according to the rotated factor loadings for PDSI in the months when the number of retained factors is >1. Isopleths of loadings 0.8 are usually indicated.
(A. May; B. June. In June that of 0.6 for the third separating region is also drawn.)

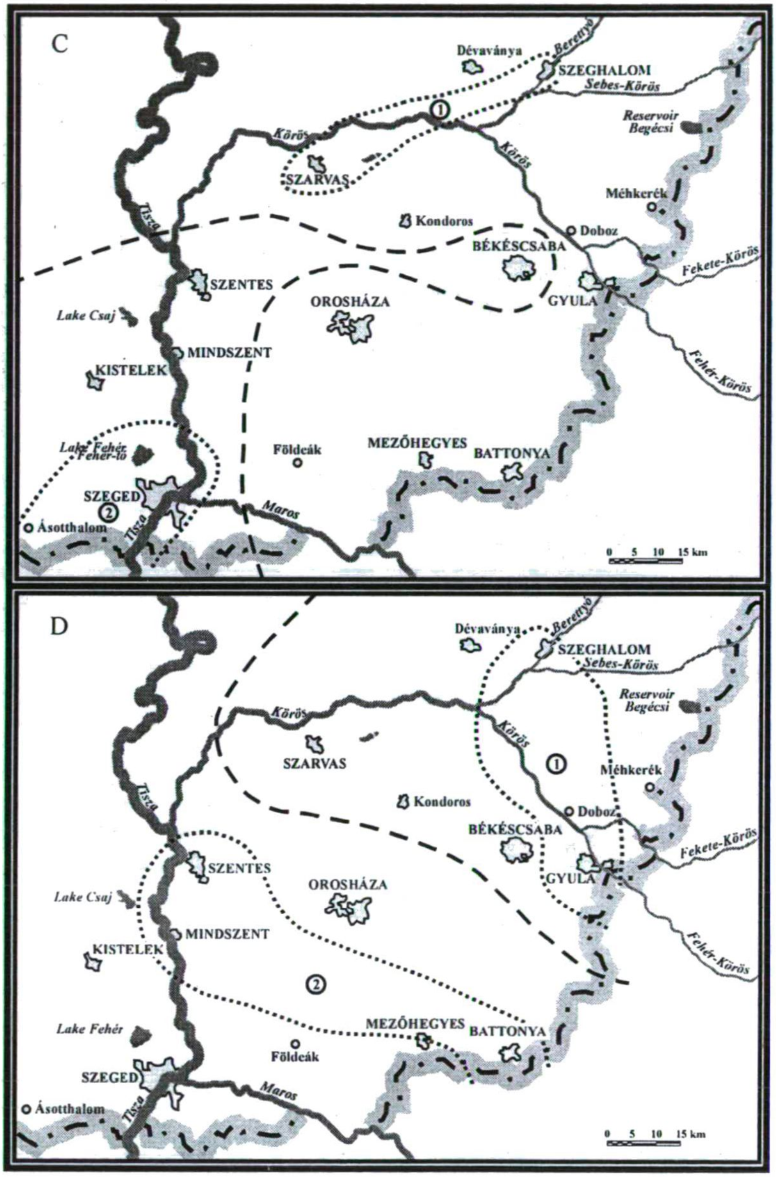

Fig. 4c-4d C. July; D. September

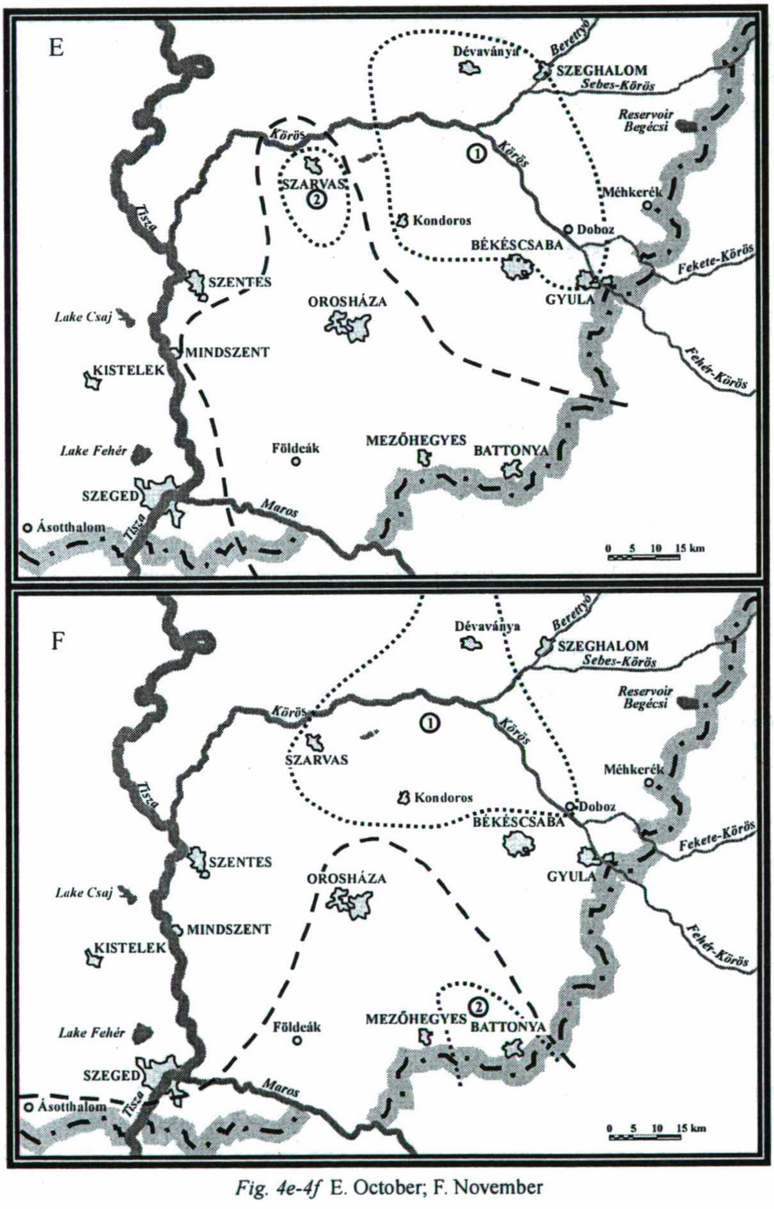

Fig. 4e-4f E. October; F. November

The regions are realistic in statistical sense. This means, that they are not direct consequences of the method, itself. This consequence is supported by the fact that in the half of the calendar months the number of regions is different. On the other hand, this fact also indicates that the obtained regions may not serve so objective basis of a landscape classification.

5. ANALYSIS OF LONG-TERM VARIATIONS

Two questions are statistically investigated in the four months-indicators of the vegetation period, for example. April, June, August and October:
i) When did significant linear trends occur during the investigated 110 years period?
ii) When did the time averages significantly differ from that in the whole period?

In both cases, Student's t-test was applied in different design. Before going into the answer of these questions, however, let us demonstrate the smoothed course of monthly PDSI during the investigated 1881-1990 period (*Fig. 5a-5b*). The applied filter is the 11 years' moving average.

In both series there is a pronounced long-term cyclicity which occured after the depression of short-term fluctuations by the 11 years moving average smoothing. PDSI at Szeged exhibited nearly 36 years' cyclicity during this 110 years period. At Szarvas, the same feature exhibit 30 years' cycles. Statistical significance of these periods requires further analyses on the original series.

The long-term, decreasing tendency of the PDSI is generally similar at the two nearly situated sites, especially at Szarvas. Another common feature is that PDSI values of the four different months vary parallel with each other at the two sites until cca. 1960. After 1960, PDSI values of April exhibit steeper decreasing tendency than those of the other months. Compared to Szeged, this difference is more characteristic in Szarvas.

5.1 Local trend analyses

Significancy of linear trends during any subperiod within the 110 years is checked by Student's t-test, as follows. Let us have the variable of Student distribution,

$$t = (b - \beta) / s_b \qquad (2)$$

Where β - the real (unknown) regression coefficient,

b - empirical regression coefficient, estimated from the finite sample,

s_b - standard deviation of the empirical estimate from the regression coefficient, b.

The zero-hypothesis is that $b = \beta = 0$, i. e. the empirical regression b does not significantly differ from 0. The statistical decision concerning this hypothesis is performed on the basis of the knowledge of the t-distribution (included into tables, in practice). The following analysis of the significance is performed at the 1 % significance level, considering that the appropriate degree of freedom is *n - 2*, where *n* is the number of elements in the sample. If the t-value,

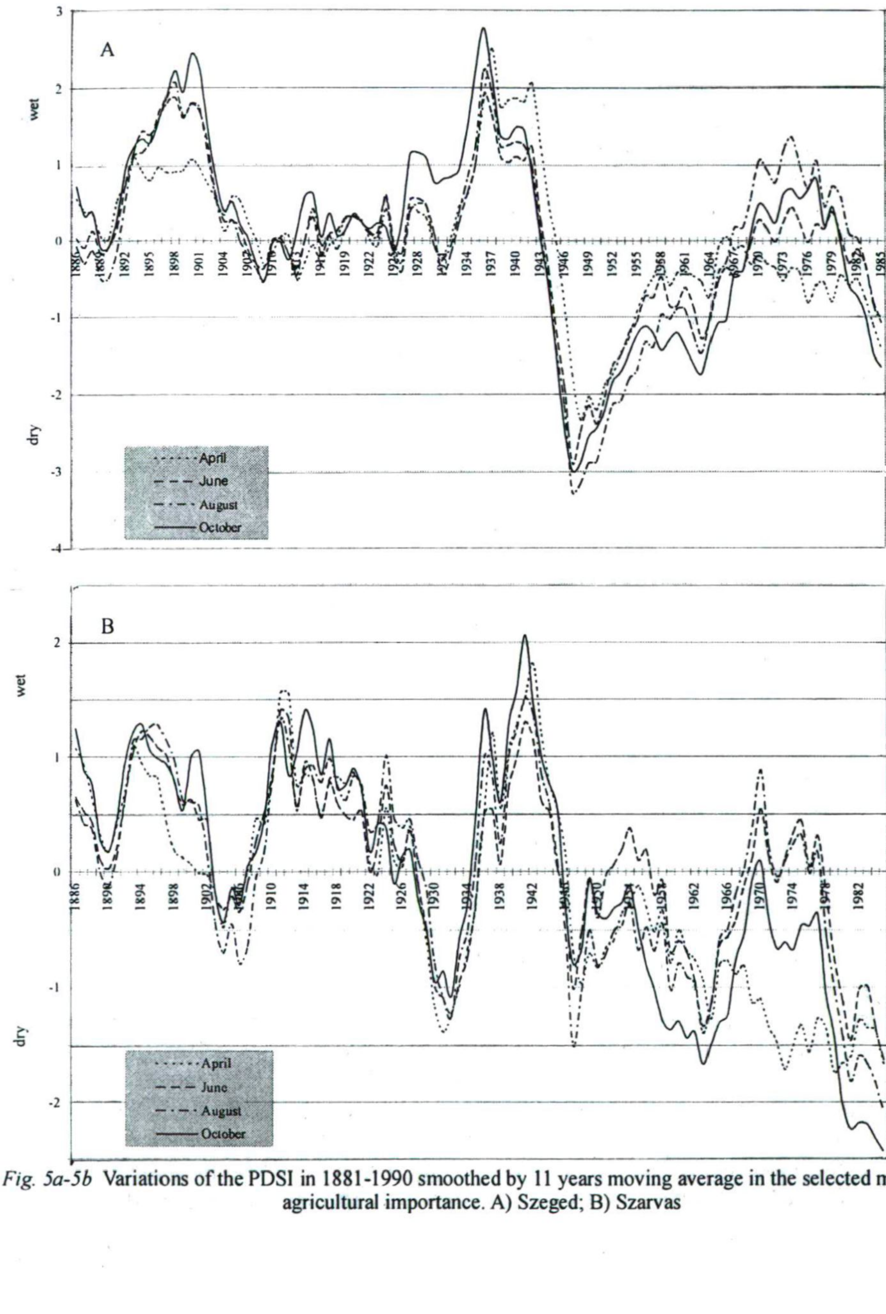

Fig. 5a-5b Variations of the PDSI in 1881-1990 smoothed by 11 years moving average in the selected months of agricultural importance. A) Szeged; B) Szarvas calculated by (2), is higher than the given threshold of the t-distribution, we consider b to be significantly different from 0. Otherwise, it is not. This test has been performed for all possible 3-110 years subperiods between 1881 and 1990.

In this way, the following can be established (*Table 5*). Linear trends of monthly PDSI series are generally significant only for relatively short 3-12 years sequences. It is also remarkable that the number of significant trends is only two, at both stations. For the longer sequences, the interannual variance is too high to allow significance of monotonous linear changes in the local series. In the table, sequence of significant periods is set in diachronic order. If comparing signs of the first and second significant periods, one can establish that they are completely different at the two sites. Decreasing (drying) trends follow the opposite ones in the first three investigated months at Szarvas, but at Szeged the situation is the opposite. This difference between the sites remains valid in October with a change of signs. Significant periods of the same sign are not much similar either in the four months or at the two sites. This means that such short sequences are yielded rather by random interannual fluctuations than by the long-term trends.

Table 5 Subperiods with significant PDSI linear trends in 1881-1990

	April	*June*	*August*	*October*
SZARVAS	1959-1967: 9 yr (+)	1934-1940: 7 yr (+)	1935-1937: 3 yr (+)	1896-1903: 8 yr (-)
	1982-1989: 8 yr (-)	1954-1965: 12 yr (-)	1954-1965: 12 yr (-)	1983-1989: 7 yr (+)
SZEGED	1908-1915: 8 yr (-)	1896-1908: 13 yr (-)	1955-1960: 6 yr (-)	1962-1965: 4 yr (+)
	1959-1967: 9 yr (+)	1960-1966: 7 yr (+)	1959-1962: 4 yr (+)	1984-1989: 6 yr (-)

5.2. A special application of Student's t-test: significant deviations of time-slices

The aim of this section is to identify subperiods' averages of which are significantly different from the 110 years mean. These subperiods were much drier or wetter than that. The point of the method is to determine the start and the termination of the significant periods. This is done for data for which the significance is still valid, irrespectively to that, which years would yield the strongest difference (i. e. among the significant ones). This search has been performed by a special case of Student's t-test, applied to detect differences between averages of non-independent series (*Makra et al.*, 1999). The significance tests have been performed at the 1 % significance level.

Contrary to those found in the previous section, length of these subperiods is much longer, which already characterizes the climate change time-scales (*Table 6*). In the four analysed months of the vegetation period, the following significant differences were detected:

It is remarkable that the number of significant periods is maximum two, at both stations. In the table, sequence of significant periods is defined in diachronic order. The signs of the first long-term periods are positive, and those of the second ones are negative in each investigated month. This means that relatively wet periods preceded the drier ones during the 110 years.

Positive (wet) deviations at Szeged occurred in April between 1887-1943 (57 years), in June between 1881-1941 (61 years), in August between 1883-1941 (59 years) and in October between 1881-1941 (61 years). At Szarvas, the wet deviations appeared between 1881-1946 (65 years) in April, between 1939-1941 (3 years !) in June, between 1881-1981 (101 years !!) in August and between 1881-1957 (77 years) in October.

Negative (dry) long periods occurred at Szeged between 1946-1990 (45 years) in April, between 1946-1990 (45 years) in June, between 1946-1990 (45 years) in August and between 1942-1990 (49 years) in October. At Szarvas, dry periods appeared between 1926-1990 (65 years), no such period existed in June, short dry period was found significant between 1982-1990 (9 years) but a fairly long one between 1928-1990 (63 years) in October. These results are in harmony with those ones according to which relative frequency of warm-dry years are incerasing in the Great Hungarian Plain between the period of 1901-1990 (*Tar*, 1993).

The experienced similarity between the long-term anomalies of identical sign in the consequtive months and at the two sites suggest that these long sequences are already yielded the long-term trends. Furthermore the decadal-scale deviation periods were wet in the first and dry in the second phase of their appearance.

This result is in full coincidence with the conclusions elaborated in a previous review paper (*Mika et al.*, 1995), declaring that the climate of the Hungarian Great Plain became drier in the more recent decades, according to series of native references.

Table 6 Subperiods with significantly different averages of PDSI from that of the full data set in 1881-1990.

	April	*June*	*August*	*October*
SZARVAS	1881-1946: 65 yr (+)	1939-1941: 3 yr (+)	1881-1981: 101 yr (+)	1881-1957: 77 yr (+)
	1926-1990: 65 yr (-)		1982-1990: 9 yr (-)	1928-1990: 63 yr (-)
SZEGED	1887-1943: 57 yr (+)	1881-1941: 61 yr (+)	1883-1941: 59 yr (+)	1881-1941: 61 yr (+)
	1946-1990: 45 yr (-)	1946-1990: 45 yr (-)	1946-1990: 45 yr (-)	1942-1990: 49 yr (-)

6. DISCUSSION

There is one possible shortcoming of the computations that may have led to non-representative conclusions. This questionable detail may be the inhomogeneity of the local temperature series that could affect the potential evaporation calculations for PDSI, especially in summer, when the inhomogeneities were the largest (Szentimrey, 1996). Even for temperature series of the chief meteorological stations this important problem could not have been found a final resolution yet.

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